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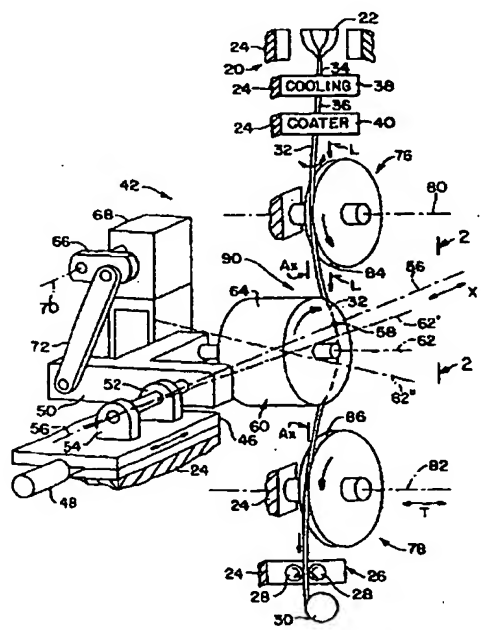
(54) Title: METHOD AND APPARATUS FOR INTRODUCING CONTROLLED SPIN IN OPTICAL FIBERS

(57) Abstract

An optical fiber (32) is drawn from a preform (22). As the fiber is being drawn, a permanent spin is imparted to it by moving one roller surface (64) relative to other surfaces (76, 78).



METHOD AND APPARATUS FOR INTRODUCING CONTROLLED SPIN IN OPTICAL FIBERS

Background of the Invention

The present invention relates to the manufacture of optical fibers.

Optical fiber used in communication systems typically includes a core of glass surrounded by a cladding also formed from glass having different optical properties from the core. The fiber typically is covered with a protective outer coating. Such fibers can be made by drawing a thin strand from a heated, partially molten preform formed from glass having the correct composition to make the core surrounded by a layer of glass having the appropriate composition to make the cladding. As a strand of soft, molten glass is pulled from the preform, both the core glass and the cladding glass stretch. The core remains in the middle and the cladding remains on the outside, thus forming the composite core and cladding structure of the finished fiber. As the fiber is pulled away from the preform, it cools and solidifies, and the coating is applied. These processes are performed at high speeds so that the fiber is drawn at high rates.

In operation of an optical communication system, light applied at one end of the fiber is pulsed or progressively varied in accordance with the information to be transmitted. The pulses or progressively varying light are

received at the other end of the fiber. The speed at which light passes along a fiber depends upon many factors including the optical properties of the materials making up the core and cladding and, the diameter of the core. The fibers commonly used for optical data transmission systems are so-called "single mode" fibers. In these fibers, the core diameter is small enough that all of the light must pass through the core in a so-called "fundamental" or "HE11" mode of transmission. Full discussion of transmission modes in optical fibers is beyond the scope of this disclosure. However, the fundamental or HE11 mode can be regarded as propagation of light straight along the axis of the core, as opposed to higher-ordered modes which can be thought of as propagation of light in a zig-zag pattern. In a theoretically perfect single mode fiber, because all of the light passes through the fiber in the same mode, all light of a given wavelength will pass along the length of the fiber with the same velocity. However, the light passing along the fiber typically includes portions having different polarizations, i.e., different orientation of the electromagnetic waves constituting the light. If the fiber core is not perfectly cylindrical, but instead is out of round so that it has long and short diameters, light of one polarization will have its electrical waves aligned with a long diameter of the core whereas light of the other polarization will have its electrical waves aligned with the short diameter of the core. In this case, the effective diameter of the fiber core will be different for light of one polarization than for light of another polarization. Portions of light having different polarizations will travel at different velocities. Stated another way, the fiber has a "slow" axis in one direction perpendicular to its length, and a "fast" axis in the other direction perpendicular to its length. Light having a direction of polarization aligned with the fast axis travels more rapidly than light having a direction of polarization aligned with the slow axis. This phenomenon is referred to in the art of fiber optic communication as polarization mode dispersion or "PMD". Imperfections in the fiber other than differences in core diameter can also contribute to PMD. PMD causes distortion of the light pulses or waves transmitted along the fiber, thus reducing the signal quality and limiting the rate at which information can be passed along the fiber.

PMD can be suppressed by providing the fiber with a "spin" so that the slow axis and the fast axis of the fiber are repeatedly interchanged along the length of the fiber. Thus, at one point along the length of the fiber the slow axis points in a first direction perpendicular to the length of the fiber and the fast axis points in a second direction perpendicular to the length of the fiber and perpendicular to the first direction. At another point along the length of the fiber, the fast axis points in the first direction and the slow axis points in the second direction. In a fiber with spin, the fast axis traces a generally helical path. The magnitude of the spin can be expressed as the number of turns per unit length of such helix, i.e., the number of times per unit length of fiber that the directions of the fast and slow axes interchange. The direction of the spin corresponds to the direction of the helix traced by the fast axis, either right-handed or left-handed. In a fiber with the appropriate spin, the effects caused by the fast and slow axes are substantially eliminated and all light travels with the same velocity. To provide optimum PMD suppression, it is normally desirable to vary the magnitude and direction of the spin along the length of the fiber.

Various attempts have been made to impart spin to the optical fiber during the production process discussed above. For example, as disclosed in Rashleigh, Navy Technical Disclosure Bulletin, Volume 5, Number 12, December 1980, Navy Tech. Cat. No. 4906, a twisted fiber can be prepared by rotating the preform about its axis while drawing the fiber from the preform. A similar approach, more generally stated as "continuous relative rotation between the preform and the drawn fiber" is disclosed in International Patent Publication WO 83/00232. As disclosed, for example, in U.S. Patent No. 4,509,968, the process involving rotation of the preform leads to considerable practical disadvantages. The preform is a massive, soft object which must be maintained at a high temperature. The '968 patent, therefore, proposes to produce a helical or "chrialic" structure in the fiber by feeding the fiber through a set of nips at the cold or downstream end of the fiber drawing process while continually spinning the frame holding the nips. A complex arrangement of a frame and fiber takeup drum

is used in this process to transfer the fiber from the spinning nips to the takeup drum.

Hart, Jr., et al. U.S. Patent Nos. 5,418,881 and 5,298,047 disclose another process for making fibers with spin of alternating clockwise and counterclockwise directions. In this process, the cold end of the fiber passes around a roller while the roller rotates about an axis perpendicular to the longitudinal or upstream-to-downstream direction of the fiber. The roller is periodically moved so that the fiber tends to roll along the surface of the roller, parallel to the axis of rotation of the roller. The fiber periodically slips or jumps along the surface of the roller. Despite these and other efforts in the art, there are still needs for further improvements in processes for imparting a controlled spin to an optical fiber. In particular, there are needs for processes which can provide non-uniform spin, and particularly alternating spins in opposite directions to the fibers in a repeatable, controllable manner. There are corresponding needs for reliable, repeatable apparatus for imparting controlled spins to fibers. In particular, there are needs for methods and apparatus which can impart appreciable spin to a fiber in a repeatable manner during high speed fiber drawing, and which can be used in combination with conventional fiber drawing equipment and processes.

The above discussion of the background to the invention herein is included to explain the context of the invention. This is not to be taken as an admission that any of the material referred to was published, known or part of the common general knowledge in Australia as at the priority date of any of the claims.

Summary of the Invention

It is an object of the present invention to provide a method and apparatus for manufacturing optical fiber, which overcomes, or at least alleviates one or more of the disadvantages of the prior art.

According to the present invention there is provided a method of providing spin in an optical fiber including the steps of:

(a) drawing the fiber so that the fiber moves relative to a frame of reference in a downstream longitudinal direction from a melt zone wherein the fiber is soft and solidifies during such downstream movement;

(b) engaging the fiber with surface regions of opposed elements disposed on opposite sides of the solidified fiber downstream from said melt zone; and

(c) moving said opposed elements so that the surface regions of said opposed elements engaged with the fiber move with components of velocity relative to said frame of reference in the downstream longitudinal direction and so that during at least part of the drawing step, at least one of said surface regions moves relative to said frame of reference in lateral directions transverse to said longitudinal direction and said surface regions move relative to one another with components of velocity in said lateral directions and thereby twist the fiber and so that the lateral components of velocity of said surface regions relative to one another are repeatedly reversed to thereby twist the fiber in alternating, opposite directions.

The present invention also provides a method of providing spin in an optical fiber including the steps of:

(a) drawing the fiber so that the fiber moves relative to a frame of reference in a downstream longitudinal direction from a melt zone wherein the fiber is soft and solidifies during such downstream movement;

(b) engaging the fiber with surface regions of a pair of opposed rollers disposed on opposite sides of the solidified fiber at a nip downstream from said

melt zone, said rollers having roller axes substantially perpendicular to the longitudinal direction;

(c) rotating said rollers about said roller axes; and

(d) translationally moving said opposed rollers relative to said frame of reference with opposite velocities in lateral directions transverse to the longitudinal direction of the fiber during at least part of the drawing step to thereby twist the fiber.

The present invention further provides a method of providing spin in an optical fiber including the steps of:

(a) drawing the fiber so that the fiber moves relative to a frame of reference in a downstream longitudinal direction from a melt zone wherein the fiber is soft and solidifies during such downstream movement;

(b) engaging the fiber with a pair of opposed rollers disposed on opposite sides of the solidified fiber at a nip downstream from said melt zone, said rollers having roller axes transverse to the longitudinal direction;

(c) rotating said rollers about said roller axes; and

(d) rocking said opposed rollers relative to said frame of reference about rocking axes transverse to the longitudinal direction of the fiber and transverse to the roller axes during at least part of the drawing step so that said roller axes tilt through substantially equal but opposite angles from perpendicular to the longitudinal direction, whereby said rotation of the rollers will twist the fiber.

The present invention further provides a method of providing spin in an optical fiber including the steps of:

(a) drawing the fiber so that the fiber moves relative to a frame of reference in a downstream longitudinal direction from a melt zone wherein the fiber is soft and solidifies during such downstream movement;

(b) engaging the solidified fiber with a first roller disposed on a first side of the solidified fiber at a first longitudinal location, said first roller having a first roller axis transverse to the longitudinal direction;

(c) engaging the solidified fiber with a pair of second rollers disposed on a second side of the fiber at locations upstream and downstream from said first location so that the first roller is longitudinally aligned with a gap between the second rollers, said second rollers having second roller axes transverse to the longitudinal direction;

(d) maintaining the solidified fiber under tension so that the fiber bears on the first and second rollers;

(e) rotating said rollers about said roller axes; and

(f) rocking said first roller relative to said frame of reference about a rocking axis transverse to the longitudinal direction of the fiber and transverse to the first roller axis during at least part of the drawing step so that said first roller axis tilts from perpendicular to the longitudinal direction, whereby said rotation of the rollers will twist the fiber.

Moreover, the present invention provides optical fiber drawing apparatus including:

(a) a structure defining a melt zone and a solid zone remote from said melt zone;

(b) means for drawing a fiber along a predetermined path in a downstream longitudinal direction relative to said structure so that the fiber is substantially molten in said melt zone and solidifies during drawing before reaching said solid zone;

(c) a pair of opposed elements disposed on opposite sides of the path in said solid zone, said opposed elements defining surface regions; and

(d) means for engaging said surface regions of said opposed elements with said fiber and moving said opposed elements during operation of said fiber drawing means so that the surface regions of said opposed elements engaged with the fiber move with components of velocity relative to said structure in said longitudinal direction, so that at least one of said surface regions moves relative to said structure in lateral directions transverse to said longitudinal direction and said surface regions move relative to one another with components of velocity in said lateral directions and thereby twist the fiber, and so said components of velocity in said lateral directions of said surface regions relative to one another repeatedly reverse to thereby repeatedly reverse the direction of twist of the fiber.

The present invention also provides optical fiber drawing apparatus including:

(a) a structure defining a melt zone and a solid zone remote from said melt zone;

(b) means for drawing a fiber along a predetermined path in a downstream longitudinal direction relative to said structure so that the fiber is

substantially molten in said melt zone and solidifies during drawing before reaching said solid zone;

(c) a first roller disposed on a first side of the path at a first roller location in said zone, said first roller being rotatable relative to said structure about said first roller axis;

(d) a pair of second rollers disposed on a second side of the path at second roller locations upstream and downstream from said first roller location said second rollers defining a gap between them, the first roller being longitudinally aligned with said gap, said second rollers being rotatable relative to said frame about second roller axes having fixed orientation parallel to one another and transverse to the longitudinal direction of said path;

(e) means for supporting said first roller on said structure so that said first roller axis is oblique to said longitudinal direction at least some times during operation of said means for drawing said first fiber, said means for drawing said fiber maintaining the fiber under tension so that the fiber will bear on said first and second rollers whereby rotation of said first and second rollers will twist the fiber.

The present invention further provides optical fiber drawing apparatus including:

(a) a structure defining a melt zone and a solid zone remote from said melt zone;

(b) means for drawing a fiber along a predetermined path in a downstream longitudinal direction relative to said structure so that the fiber is substantially molten in said melt zone and solidifies during drawing before reaching said solid zone;

(c) a pair of opposed rollers disposed on opposite sides of the path and defining a nip in said solid zone, each of said rollers having a roller axis and a circumferential surface encircling the roller axis, each said roller being rotatable about its roller axis;

(d) means for supporting said rollers on said structure so that at least some time during operation of said drawing means, said roller axes are disposed at oppositely directed oblique angles to the longitudinal direction of said path;

(e) means for forcibly engaging said circumferential surfaces of said rollers with a fiber drawn along said path by said fiber drawing means, whereby rotation of said rollers about said roller axes will cause the fiber to twist.

The present invention further provides optical fiber drawing apparatus including:

(a) a structure defining a melt zone and a solid zone remote from said melt zone;

(b) means for drawing a fiber along a predetermined path in a downstream longitudinal direction relative to said structure so that the fiber is substantially molten in said melt zone and solidifies during drawing before reaching said solid zone;

(c) a pair of opposed rollers disposed on opposite sides of the path and defining a nip in said solid zone, each of said rollers having a roller axis transverse to the longitudinal direction and a circumferential surface encircling the roller axis, each said roller being rotatable about its roller axis;

(d) means for supporting said rollers on said structure and moving said rollers relative to one another in opposite lateral directions transverse to the longitudinal direction at least some times during operation of said drawing means; and

(e) means for forcibly engaging said circumferential surfaces of said rollers with a fiber drawn along said path by said fiber drawing means, whereby rotation of said rollers about said roller axes will cause the fiber to twist.

The present invention further provides an optical fiber drawing apparatus, including:

(a) a furnace adapted to hold and melt a preform from which a fiber is drawn along a predetermined path in a longitudinal direction; the fiber being substantially molten within a melt zone of the furnace and is solidified along the path;

(b) a pair of opposed rollers between which the fiber passes disposed on opposite sides of the path, the fiber being engaged by the rollers, each of the rollers having a roller axis transverse to the longitudinal direction and being rotatable about its roller axis; and

(c) mounts supporting and moving the rollers relative to one another in opposite lateral directions transverse to the longitudinal direction at selected times during fiber draw thereby imparting spin to the fiber.

Accordingly, one aspect of the present invention includes methods of providing spin in an optical fiber. An embodiment according to this aspect of the invention includes the step of drawing the fiber so that the fiber moves, relative to a frame of reference, downstream in a longitudinal direction from a melt zone in which the fiber is soft. The fiber solidifies during this downstream movement. The method further includes the steps of engaging the fiber with surface regions of opposed elements disposed on opposite sides of the solidified fiber downstream from the melt zone and moving these opposed elements so that surface regions of the opposed elements engaged with the fiber move with components of velocity, relative to the frame of reference in the downstream

longitudinal direction. The motion is controlled so that during at least part of the drawing step, at least one of the surface regions moves relative to the frame of reference in a lateral direction transverse to the longitudinal direction of the fiber movement and so that the surface regions engaged with the fiber on opposite sides move relative to one another with opposite components of velocity in lateral directions to thereby spin the fiber. Most preferably, the moving step is conducted so that the lateral components of velocity of the surface regions relative to one another are repeatedly reversed, so that the fiber is spun repeatedly in alternating, opposite directions.

Preferably, the step of moving the opposed elements is performed so that the surface region on a first one of the opposed elements moves in a first surface motion direction oblique to the longitudinal direction of the fiber during at least part of the drawing step. Most preferably, the fiber is forcibly engaged with the surfaces of the opposed elements.

According to one embodiment of the invention, the step of moving the first element includes the step of moving this first element around a first element axis generally transverse to the longitudinal direction so that the surface region of the first element engaged with the fiber moves perpendicular to this first element axis. For example, the first element may be a roller having a circumferential surface concentric with the first element axis, and the step of moving the first element may include the step of rotating the roller about the first element axis. The first element may also be a belt and the step of moving the first element may include the step of moving the belt around a pulley while the pulley rotates about the first element axis. In either case, the step of moving the first element axis may include the step of rocking the first element, and the first element axis, about a rocking axis transverse to the longitudinal direction of the fiber and also transverse to the aforesaid lateral directions. The rocking axis typically is perpendicular to the first element axis. The surface region of the first element may be a region on the circumferential surface of the roller or on the surface of the belt. When the first element axis rocks about the rocking axis, the direction of motion of this surface portion engaging the fiber (the "first surface motion direction") will sweep through